

P-1084

Title of Invention

PROCESS FOR PRODUCTION OF MOLECULAR SIEVE ADSORBENT BLENDS

Cross reference to related applications

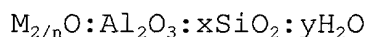
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Background of Invention**1. Field of Invention**

This invention relates to molecular sieve adsorbents and more particularly to a molecular sieve adsorbent blend comprising a zeolite and a highly dispersed attapulgite binder. This invention also relates to a process for the preparation of a molecular sieve adsorbent blend comprising blending a zeolite with a highly dispersed attapulgite binder.

**2. Background Art**

Zeolites are hydrated metal alumino silicates having the general formula



where M usually represents a metal of the alkali or alkaline earth group, n is the valence of the metal M, x varies from 2 to infinity, depending on the zeolite structure type and y designates the hydrated status of the zeolite. Most zeolites are three-dimensional crystals with a crystal size in the range of 0.1 to 30  $\mu m$ . Heating these zeolites to high temperatures results in the loss of the water of hydration, leaving a crystalline structure with channels of molecular dimensions, offering a high surface area for the adsorption

of inorganic or organic molecules. Adsorption of these molecules is limited by the size of the zeolite channels. The rate of adsorption is limited by the laws of diffusion.

One limitation on the utilization of these zeolite crystals is their extremely fine particle size. Large naturally-formed agglomerates of these crystals break apart easily. Because the pressure drop through the bed is prohibitively high, these zeolite crystals cannot be used in fixed beds for various dynamic applications, such as drying of natural gas, drying of air, separation of impurities from a gas stream, separation of liquid product streams and the like. Therefore, it is desirable to agglomerate these crystals with other materials to provide an agglomerate mass of the crystals which exhibits a reduced pressure drop.

To permit the utilization of these molecular sieve crystals, different types of clays are used as binders including attapulgite, palygorskite, kaolin, sepiolite, bentonite, montmorillonite and mixtures thereof. For example, U.S. Patent No. 2,973,327 discloses the use of a number of different types of clays, including attapulgite, as a binder for molecular sieves. The clay content of the bonded molecular sieve can vary from as low as 1 percent to as high as 40 percent by weight, although the preferred range is from about 10 to about 25 percent by weight.

U.S. Patent No. 3,219,590 discloses another molecular sieve blend comprising a kaolin-type clay and a lignosulfonate which functions as the binding agent.

5 Adsorbent materials comprising a type 5A zeolite molecular sieve and a kaolin clay binder, wherein the kaolin comprise from about 10 to about 40 percent of the composition, are disclosed in U.S. Patent No. 5,001,098.

Molded bodies containing dealuminated zeolite Y and a binder material are disclosed in U.S. Patent No. 5,316,993.

10 An adsorbent and/or catalyst blended with a binder system comprising a colloidal metal oxide, an oxide adsorbent and an acid are disclosed in U.S. Patent No. 5,948,726.

15 An adsorbent for separating gases comprising a binder and a crystalline, low silica faujasite-type zeolite with a silica to alumina molar ratio of 1.9 to 2.1 is disclosed in EP 0 940 174 A2.

20 An abrasion-resistant granular zeolite formed by blending a zeolite and a binder system is disclosed in U.S. Patent No. 4,420,419. See also U.S. Patent No. 5,292,360 which discloses an adsorbent for the purification of gases comprising a 5A zeolite molecular sieve and a kaolin clay binder.

25 One problem with conventionally formed zeolite blends is decreased diffusion. The larger the diameter of the

5 formed zeolites, the slower the rate of diffusion of the molecules to be adsorbed. Particularly in the field of pressure swing adsorption, this effect is highly adverse to short cycle time and thus to productivity. Enhanced kinetic values or faster mass transfer rates can result in shorter cycle time and lower power consumption and thus higher adsorbent productivity.

10 It has been recognized that a reduction in the particle size of formed zeolites leads to shorter mass transfer zones and shorter cycle times. This is based on the assumption that the time needed for adsorbates to travel through the macropores of the adsorbents limits the cycle time, i.e. macropore diffusion is the rate limiting step in these processes. This problem can be improved by adding pore forming compounds to the zeolite clay blend before the forming step.

15 Accordingly it is an object of the invention to disclose a process for the preparation of molecular sieve adsorbents with enhanced diffusion rates.

20 It is a still further object of the invention to disclose a process for the production of a molecular sieve adsorbent blend which is especially useful in thermal swing adsorption (TSA) systems and in pressure swing adsorption (PSA) systems.

25 It is a still further object of the invention to

disclose molecular sieve adsorbent blends which maintain their physical properties and diffusion capabilities even with reduced binder percentages.

5 It is a still further object of the invention to disclose a process for the production of a molecular sieve adsorbent blend utilizing highly dispersed attapulgite fibers.

10 It is a still further object of the invention to disclose a molecular sieve adsorbent blend comprising a zeolite powder and a highly dispersed attapulgite binder.

15 It is a still further object of the invention to disclose a process for drying a feed stream comprising passing the feed stream over a molecular sieve adsorbent blend comprising a zeolite and a highly dispersed attapulgite binder.

20 It is a still further object of the invention to disclose a process for the adsorption of carbon dioxide from an air stream comprising passing that air stream over a molecular sieve adsorbent blend comprising a zeolite powder and a highly dispersed attapulgite binder.

25 It is still further object of the invention to disclose a process for separation of components of a gaseous or liquid feed stream comprising passing that gaseous or liquid feed stream over a molecular sieve adsorbent blend comprising a zeolite powder and a highly dispersed

attapulgit binder.

These and other objects are obtained by the process for production, the process for use and product of the invention disclosed herein.

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### Summary of the Invention

The present invention is a process for the production of a molecular sieve adsorbent blend with improved performance characteristics comprising

10 preparing a zeolite,

preparing an attapulgit binder containing highly dispersed attapulgit fibers,

mixing the zeolite with the attapulgit binder in an aqueous mixture,

15 forming molecular sieve adsorbent products from the mixture, and

calcining the adsorbent product to form a molecular sieve adsorbent blend, wherein the tapped bulk density of the highly dispersed attapulgit fibers, is above 550 g/l as measured according to DIN/ISO 787, and wherein the water adsorption capacity of the highly dispersed binder is above 35 percent (w/w).

20 The present invention is also a molecular sieve adsorbent blend comprising

25 a zeolite blended with a highly dispersed

attapulгите binder, wherein the tapped bulk density of the highly dispersed attapulгите binder is above 550 g/l as measured according to DIN/ISO 787, and wherein water adsorption capacity of the highly dispersed binder is above 35 percent (w/w).

The present invention is also a process for drying a feed stream comprising passing the feed stream over a molecular sieve adsorbent blend comprising a zeolite blended with a highly dispersed attapulгите binder as defined above.

The invention is also a process for the separation of components of a gaseous or liquid feed stream comprising passing the liquid feed stream over a molecular sieve adsorbent blend comprising a zeolite blended with a highly dispersed attapulгите binder as defined above.

#### **Detailed Description of the Invention**

The present invention is a molecular sieve adsorbent blend formed from a zeolite blended with a highly dispersed attapulгите binder and a process for formation of that product. The invention is based on the discovery that the adsorption rate of a molecular sieve product is not only dependent upon the size of the formed zeolite particles, but also the type and characteristics of the binder blended with the zeolite. It has been surprisingly discovered that the

same type and quantity of zeolite when blended with different binders produces zeolite blends which exhibit different adsorption characteristics depending upon the binder that is used. The phrase "adsorption rate" or "sorption rate" or "mass transfer rate" means the rate at which an adsorbate loading in a feed stream changes over a given period of time for a given adsorption separation process.

The prior art suggests that the adsorption rate of a molecular sieve adsorbent is only a function of the porosity and particle size of the molecular sieve adsorbent. It has now been surprisingly discovered that the type of binder that is used to bind the zeolite crystals also plays a role in the adsorption rate of the zeolite material.

Adsorbent aggregates or blends are formed by mixing zeolite crystals with binder materials. Various types of zeolites may be used to form the adsorbent blend including zeolite A, zeolite X, zeolite Y, zeolite ZSM-5, zeolite Beta, synthetic mordenite and blends thereof. These zeolites may be used singly or in mixtures of two or more zeolites. Zeolites may be present in their alkali or alkaline earth metal substituted form. The particular type of zeolite present in the blend depends upon the adsorbate that is to be adsorbed from the feed stream. For example, when the desired adsorbent is carbon dioxide in a gas



stream, the preferred zeolites include zeolite X or zeolite  
LSX. When the adsorption process is for the purification of  
gases, notably by pressure swing adsorption (PSA) and  
temperature swing adsorption (TSA) methods, the preferred  
zeolites include zeolite A or zeolite X.

Binder materials are utilized to bind the individual  
zeolite crystals together, to form shaped products and to  
reduce the pressure drop during adsorption. However, in the  
past the binder material has not enhanced the adsorption  
capability of the zeolite. In fact, conventional binder  
materials have generally reduced the adsorption capacity of  
the zeolites. Binder materials which have been utilized  
with zeolites in the past include clay minerals, such as  
kaolin, palygorskite-type minerals, such as attapulgite, and  
smectite-type clay minerals, such as montmorillonite or  
bentonite. These clay binders have been used singly or in  
mixtures of two or more different types of clay binders.

The inventors have discovered that a particularly  
useful blend of zeolites and a clay binder is produced when  
the clay material is an attapulgite clay which has been  
"highly dispersed." Generally speaking, clay particles,  
especially attapulgite clay particles, exist as dense  
materials with very limited adsorption capabilities. These  
conventional clay binder particles are different in size and  
shape from the zeolite particles. When blended with zeolite

crystals they tend to occupy space between the zeolite crystals and may assist in the adsorption by the zeolite material without increasing the overall adsorption of the zeolite blend.

5           In particular, attapulgite clay particles, even after mining and work-up, are naturally formed in the shape of dense bundles of clumped bristles. The existence of these bundles has been confirmed using scanning electron microscopy (SEM). These bristles must be separated or  
10 ground to permit their use as binders for zeolite particles. Without grinding these attapulgite clay particles to a smaller size, a non-porous layer of attapulgite clay particles is created in the zeolite blend, preventing or substantially limiting, diffusion of adsorbates through the  
15 blend. The conventional attapulgite clays that have been utilized in the past are produced by dry grinding the attapulgite clay. In the conventional process these dry ground attapulgite clay bundles of bristles are then blended with the zeolite crystals. However, even after this  
20 conventional grinding of the attapulgite clay bundles, large bundles of attapulgite clay bristles are still present. When these conventional attapulgite clay bundles are blended with zeolite and formed into adsorbents, the capability of the zeolite materials to adsorb the desired adsorbate is not  
25 substantially enhanced.

The applicants' invention utilizes "highly dispersed" attapulgite clay as the binder material that is blended with the zeolite powder. The difference between conventional, dense attapulgite clay bundles and the "highly dispersed" attapulgite clay particles of the invention can be differentiated readily through the use of a scanning electron microscopy. Another method to distinguish between conventional dense attapulgite clay and the "highly dispersed" attapulgite clay products of the invention is by the use of tapped bulk density measurement as determined according to DIN/ISO 787. Dense attapulgite clay binders contain a residual water content of about 20-25 percent and have a tapped bulk density of about 400 g/l to about 530 g/l. "Highly dispersed" attapulgite binders also contain residual water of about 20-25 percent but have a tapped bulk density of about 550 g/l to about 700 g/l.

Another method to distinguish between conventional dense attapulgite clay and highly dispersed attapulgite clay products of the invention is by determining the water adsorption capacity of the attapulgite clay products. To determine whether the clay binder is "highly dispersed" the clay binder is fully saturated at 50 percent relative humidity at 25°C to the point where an equilibrium adsorption capacity is achieved. This process may take up to 72 hours. After full hydration of the clay is achieved the clay is

dried at 550°C for at least two hours. The difference of the weight between the fully hydrated clay and the dried clay is the water adsorption capacity. For dense attapulgite clays, the water adsorption capacity is below 30 percent whereas for the "highly dispersed" attapulgite clay, the water adsorption capacity is above 35 percent.

While any process which produces attapulgite fibers which are "highly dispersed" as defined above is within the scope of the invention, one preferred process is disclosed in U.S. Patent No. 6,130,179, the contents of which are incorporated by reference into this application. This patent fails to disclose or suggest the use of this highly dispersed attapulgite clay with zeolite. The process of U.S. Patent No. 6,130,179 utilizes a dispersant which disperses the individual attapulgite particles in water such that they remain in suspension even after other materials, including other clay and mineral species, are removed from that solution. Once the "highly dispersed" attapulgite clay is prepared, it is ready for use in the production of the molecular sieve adsorbent product of the invention.

Generally the process to produce the molecular sieve adsorbent blend product with improved performance characteristics according to the invention is as follows:

prepare the zeolite material,

prepare an attapulgite binder comprising highly

dispersed attapulgite fibers,

mix the zeolite with the attapulgite binder in an aqueous mixture,

form an uncalcined material from the mixture, and

5 calcine the material to form the molecular sieve adsorbent blend product of the invention.

Once the appropriate zeolite material is chosen for a given application, it is mixed with the highly dispersed attapulgite binder in the presence of water. The zeolite powder and the highly dispersed attapulgite binder are blended together with water. The amount of highly dispersed attapulgite binder that is utilized can range from 5 to about 30 percent by weight, preferably from about 5 to about 20 percent and most preferably in the range of about 10 percent of the blend. Conventional mixtures of zeolite and non-highly dispersed attapulgite clay binders utilize about 20 percent or more attapulgite clay. Sufficient water is retained in or added to the mixture to make a formable mixture, i.e., one that can be easily extruded.

20 The mixture is blended using a conventional blending device, such as a conventional mixer, until a mass of suitable viscosity for forming is obtained. The blended mixture is then formed into the appropriate shaped product, for example, by extrusion. The products can be formed in  
25 any conventional shape such as beads, pellets, tablets or

other such conventional shaped products. Once the formed products are produced into the appropriate shape, they are calcined, preferably at about 600°C, for about 30 minutes to 2 hours.

5 In an optional preferred embodiment, a pore forming agent may be added to the zeolite/attapulgite clay mixture during the mixing step to enhance the total pore volume of the end product. Among the acceptable pore forming agents are fibers, including rayon, nylon, sisal, flax and the like and organic polymers, including corn starch, starch derivatives, lignosulfonates, polyacrylamide, polyacrylic acid, cellulose, cellulose derivatives and the like. The amount of the pore forming agent that may be added is from about 2 to about 15 percent, by weight.

Products produced by the process of the invention show improved adsorption rates. The adsorption rate can be determined using several different methods. For example, in one preferred process, the adsorbent product produced according to the invention can be tested to determine the  
20 time necessary to achieve 95 percent of the maximum adsorption capacity of the material. The shorter the time to achieve this value, the faster the adsorption rate.

In another process to determine the adsorption rate of the molecular sieve adsorbent blend of the invention, the  
25 amount of the adsorbed product that has been adsorbed over

a given period of time can be determined.

In a further process of comparison of adsorption, the mass transfer zone of the blend of the invention can be compared to that of a conventional blend under given conditions. The shorter the mass transfer zone, the higher the adsorption rate.

Finally, the diffusion rate can be determined directly for certain gases or liquids. The higher the diffusion rate, the faster the adsorption rate.

It has been surprisingly discovered that by replacing a conventional attapulgite binder with the same quantity of "highly dispersed" attapulgite binder of the invention, there is an improved adsorption rate regardless of which method is used to measure that rate. The improvement in adsorption rate is at least about 10 percent and as high as 200 percent compared to products containing conventional attapulgite clay binders. This improvement is especially important because of the increased cost of the highly dispersed attapulgite binder over conventional attapulgite binders.

A further surprising improvement is in the ability of the zeolite adsorbent blend product to maintain its crush strength even when the amount of the attapulgite binder that are added to the mixture is reduced. Generally speaking, the more binder that is present in the forming process, the

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better the crush strength for the finished product. For conventional dense attapulgite binders, this improvement in the crush strength is dramatic when the percentage of attapulgite binder within the end product increases from zero to about 20 percent of the composition. Products made with conventional dense attapulgite binder of 10 percent or less are not practical as their crush strength drops below acceptable levels. It has been surprisingly discovered that a product produced using the highly dispersed attapulgite fibers of the invention produces an end product with adequate crush strength even when the quantity of the highly dispersed attapulgite binder in the end product is as low as 10 percent or less. Further, at any particular percentage of binder material, the crush strength of a product produced using the highly dispersed attapulgite fiber of the invention is higher than for a product made with a conventional dense attapulgite binder.

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It has also been surprisingly discovered that even when lower percentages of a highly dispersed attapulgite fiber are utilized in an adsorbent product, the rate of water adsorption increases. This is evidenced by a reduction in the amount of time that is necessary to achieve a particular predetermined amount to be adsorbed. This improvement is at least 10 percent and in many cases as much as 30 percent or more.



5 The highly dispersed attapulgite binder can be blended  
with zeolite and used for a number of different processes.  
For example, the blend of highly dispersed attapulgite clay  
and zeolite can be used for drying a feed stream, such as  
for the removal of water from a gaseous or liquid ethanol  
stream. The blend can also be used for the separation of  
nitrogen from an air stream. Further, the blend can be used  
for the removal of sulfur and oxygen containing compounds  
from a hydrocarbon stream. Another use for this blend is  
10 for the removal of carbon monoxide, carbon dioxide and  
nitrogen from a hydrogen gas stream. The blend can also be  
used for the removal of water from a gaseous or liquid  
hydrocarbon stream or for the removal of water from a  
gaseous or liquid stream of refrigerants. Another use is  
15 for the removal of water and carbon dioxide from air. The  
adsorbent material of the invention may also be used for the  
separation of organic compound, such as for the separation  
of n-paraffins from a mixture of iso-paraffins and n-  
paraffins or for the conversion of certain organic  
20 compounds. There are a number of other processes for which  
this blend of a highly dispersed attapulgite clay and  
zeolite can be utilized which would be well known to a  
person skilled in the art and which are covered by this  
invention.

25 These improvements are shown by the following examples:

**EXAMPLES****Example 1**

Samples of an attapulgite clay material that is conventionally used as a binder for zeolites and a highly dispersed attapulgite clay material were tested for tapped bulk density, residual water and water adsorption capacity. Tapped bulk density was determined according to DIN/ISO 787. (Actigel 208 obtained from ITC Floridin was used as the highly dispersed attapulgite clay in all examples. The conventional attapulgite clays were of different brands and obtained from ITC Floridin.)

A clay sample of about 10 grams was weighed in a porcelain crucible (weighing precision 1 mg) and heated to 550°C for 2 hours. The sample was cooled to room temperature in a desiccator and weighed (weighing precision 1 mg). The weight difference led to the residual water amount.

Another clay sample of about 10 grams was weighed in a porcelain crucible (weighing precision 1 mg) and was water saturated at 50 percent relative humidity and 20°C. The equilibrium was reached within 72 hours. The sample was weighed (weighing precision 1 mg) and heated to 550°C for 2 hours. The sample was cooled to room temperature in a desiccator and weighed (weighing precision 1 mg). The weight difference of the fully hydrated sample and fully dried sample led to the water adsorption capacity given in

Table 1 below. The fully dried mass was taken as 100 percent clay.

**Table 1**

<b>Attapulgitic Clay Sample</b>				
	Highly Dispersed Clay	Conventional Dense Clay 1	Conventional Dense Clay 2	Conventional Dense Clay 3
Tapped Bulk Density (g/ml)	617 595 660	398 + 31 (average of 17 samples)	529 + 20 (average of 21 samples)	428 459
Residual Water as Received (%)	22.3 21.7 23.7	25.5	21.4	25.5 22.6
Water Adsorption Capacity (%)	36.8 36.0 36.0	28.8	25.0	29.7 28.8

As is clear from the Table, the bulk density of the highly dispersed clay was significantly higher than the bulk density of the conventional dense attapulgitic clay. In addition, the water adsorption capacity of the highly dispersed attapulgitic clay was significantly higher than that of the conventional dense attapulgitic clay.

**Example 2**

The crush strength of samples of a molecular sieve adsorbent blend product prepared using a conventional dense attapulgitic clay was compared with a molecular sieve adsorbent blend product prepared using a highly dispersed

attapulgite clay.

To determine the crush strength of the various samples, molecular sieve blends were prepared. Sodium A molecular sieve was blended with various amounts of both a conventional dense attapulgite clay and the highly dispersed attapulgite clay. To 100 grams of the molecular sieve/clay binder mixture about 30 to 40 grams of water were added and then blended for up to 180 minutes using a conventional blender. The product was then extruded in the form of 1/16" extrudates. These extrudates were then dried at approximately 120°C for 8 to 12 hours and then calcined at 600°C for about 2 hours.

**Table 2**

**Crush Strength in Relation to the Amount of Binder Used**

	Conven- tional Dense Binder (20%)	Conven- tional Dense Binder (15%)	Conven- tional Dense Binder (10%)	Highly Dispersed Binder (20%)	Highly Dispersed Binder (15%)	Highly Dispersed Binder (10%)
Size of Extrudates	1/16"	1/16"	1/16"	1/16"	1/16"	1/16"
Crush Strength [N]	19.9	8.8	7.5	28.5	19.6	16.1

Surprisingly the crush strength of a product made with 20 percent highly dispersed attapulgite fibers was significantly greater than a product made with the same

percentage of a conventional dense attapulgite binder. Further, the crush strength remained at a reasonably high level even when the amount of the highly dispersed attapulgite fiber was reduced to 10 percent, whereas the crush strength of the material using the conventional attapulgite binder dropped rather significantly.

### **Example 3 - Water Adsorption Kinetics**

The materials prepared in Example 2 were tested for water adsorption kinetics. It was surprisingly discovered that the amount of binder did not have an impact on the water adsorption kinetics of the material made with the conventional binder. In contrast, it was surprisingly discovered that when the amount of the highly dispersed attapulgite fiber was reduced to 10 percent, the rate of adsorption of water to reach 95 percent of adsorption capacity increased dramatically. Details are shown in the attached Table 3.

**Table 3**  
**Influence of Binder Type and Binder Amount**  
**to Water Adsorption Kinetics**

	Conven- tional Dense Binder (20%)	Conven- tional Dense Binder (15%)	Conven- tional Dense Binder (10%)	Highly Dispersed Binder (20%)	Highly Dispersed Binder (15%)	Highly Dispersed Binder (10%)
Size of Extrudates	1/16"	1/16"	1/16"	1/16"	1/16"	1/16"
H <sub>2</sub> O Adsorption Kinetics at 1 mbar [min]	121	130	122	136	133	96

**Example 4 - Beaded Molecular Sieve 3A**

A premixed zeolite 3A powder/attapulgitic clay composition was added continuously to a granulation pan. The zeolite 3A powder was acquired from CU Chemie Uetikon AG. During the beading process, water was sprayed on the powder mixture to maintain a constant humidity. The powder mixture was added at a speed of 300 kg/hr. After having finished the addition of the powder mixture, the beads were rolled for another 10 minutes. The green beads were dried at 100°C and then calcined at 600°C. The calcined beads were stored in well closed containers and analyzed. Table 4 gives the comparative results for the two different beaded materials. While physical properties, such as crush strength and bulk density were generally the same for both samples, mass transfer zone was reduced significantly and water adsorption rate was surprisingly faster for the

product made with the highly dispersed attapulgite clay.

**Table 4**  
**Comparative Results of a Conventional 3A Molecular Sieve and a Molecular Sieve Produced with 10% Highly Dispersed Attapulgite Clay as a Beneficiated Attapulgite Binder**

	Reference Material (20% Dense Attapulgite Binder)	According to Invention (10% Highly Dispersed Attapulgite Clay)
Bead Size [mesh]	4 x 8	4 x 8
Crush Strength [N]	51	46
Bulk Density [g/l]	721	687
Water Adsorption 50% r.h. [%]	20.1	21.3
Water Mass Transfer Zone [mm]	253	167
Water Adsorption Kinetic (time to reach 95% ads. capacity; 4 mbar) [min]	184	105

**Example 5**  
**Beaded Molecular Sieve 3A for Natural Gas Drying**

A premixed zeolite 3A powder/organic additive/clay composition was added continuously to a granulation pan. During the beading process, water was sprayed onto the powder mixture to keep a constant humidity. The powder mixture was added at a speed of 300 kg/hr. After having finished the addition of the powder mixture, the beads were rolled for another 10 minutes. The green beads were dried at 100°C and then calcined at 630°C. The calcined beads

were stored in closed containers and analyzed. The amount of organic additive was kept constant for both experiments. Table 5 gives the comparative results of the two different beaded materials. While physical properties, attrition, and bulk density are generally the same for both samples, water adsorption rate increased surprisingly for the product produced using the highly dispersed attapulgite clay. The beads are much smaller than in Example 4, but the increase in the adsorption rate was still very high, indicating that the effect is intrinsic.

Table 5

**Comparative Results of a Conventional 3A Molecular Sieve Used for Natural Gas Drying and a Molecular Sieve Produced with 10% Highly Dispersed Attapulgite Clay as a Beneficiated Attapulgite**

	Reference Material (20% Conventional Dense Attapulgite Binder)	According to Invention (10% Highly Dispersed Attapulgite Clay)
Bead Size [mesh]	8 x 12	8 x 12
Attrition [%]	0.04	0.02
Bulk Density [g/l]	730	722
Water Adsorption 50% r.h. [%]	22.2	22.7
Water Adsorption Kinetic at $p/p_0=0.03$ , after 120 min. [%]	14.1	18.5



**Example 6 - Beaded Molecular Sieve 5A**

A premixed zeolite 5A powder/clay composition was added continuously to a granulation pan. The zeolite 5A powder was acquired from Zeochem Ltd. During the beading process, water was sprayed onto the powder mixture to keep a constant humidity. The powder mixture was added at a speed of 300 kg/hr. After having finished the addition of the powder mixture, the beads were rolled for another 10 minutes. The green beads were dried at 100°C and then calcined at 630°C. The calcined beads were stored in closed containers and analyzed. Table 6 gives the comparative results of the two different beaded materials. While butane adsorption capacity increased within expectations, nitrogen adsorption kinetic increased surprisingly, certainly more than was anticipated.

**Table 6**  
**Comparative Results of a Conventional 5A Molecular Sieve and a Molecular Sieve Produced with 10% Highly Dispersed Attapulgite Clay as a Beneficiated Attapulgite Binder**

	Reference Material (20% Conventional Dense Attapulgite Binder)	According to Invention (10% Highly Dispersed Attapulgite Clay)
Bead Size [mesh]	8 x 12	8 x 12
N-Butane Adsorption Capacity; 1 bar/25°C [%]	8.0	9.3
Nitrogen Kinetic Value [1/s]	0.17	0.39

**Example 7 - Beaded Molecular Sieve 4A**

The same preparation procedure was used as in Example 6, except that zeolite 4A powder acquired from CU Chemie Uetikon was used for the beading process. The amount of the binder for the new formulation was increased to 15%. The drying and the calcination process followed the same temperature profiles as was used in Example 6. The results are given in Table 7. The Example using 15% of the highly dispersed attapulgite binder showed a surprising improvement in the adsorption rate. The mass transfer zone dropped from 137 mm to 106 mm and the water adsorption capacity after 120 minutes increased from 15.0% to 17.2%.

**Table 7**  
**Comparative Results of a Conventional 5A Molecular Sieve and a Molecular Sieve Produced with 15% Highly Dispersed Attapulgite Clay as a Beneficiated Attapulgite Binder**

	Reference Material (20% Conventional Dense Attapulgite Binder)	According to Invention (15% Highly Dispersed Attapulgite Clay)
Bead Size [mm]	2 - 3	2 - 3
Crush Strength [N]	57	41
Attrition [%]	0.03	0.01
Bulk Density [g/l]	729	710
Water Mass Transfer Zone [mm]	137	106
Water Adsorption Kinetic at $p/p_0$ (after 120 min.) [%]	15.0	17.2

**Example 8**  
**Beaded Molecular Sieve 13X Used**  
**for Air Purification and/or for Air Separation**

A premixed zeolite 13X powder/organic additive/clay composition was added continuously to a granulation pan. The 13X zeolite powder was acquired from CU Chemie Uetikon AG. During the beading process, water was sprayed onto the powder mixture to keep a constant humidity. The powder mixture was added at a rate of 500 kg/hr. After having finished the addition of the powder mixture, the beads were rolled for another 10 minutes. The green beads were dried at 100°C and then calcined at 620°C. The calcined and cooled beads were stored in air tight containers and analyzed. The analytical results of the finished product are given in Table 8. Again, the physical properties remained within expectations, but the adsorption rate increased for the composition of the invention much more than expected, especially for the adsorption of nitrogen.

**Table 8**  
**Comparative Results of a Conventional 13X Molecular Sieve Used for Air Prepurification and for Air Separation, and a Molecular Sieve Produced with 10% Highly Dispersed Attapulgite Clay as a Beneficiated Attapulgite Binder**

	Reference Material (16% Dense Conventional Attapulgite Binder)	According to Invention (10% Highly Dispersed Attapulgite Clay)
Bead Size [mm]	1.0 - 2.0	1.0 - 2.0
Attrition [%]	0.05	0.07
Bulk Density [g/l]	640	638
Water Adsorption Capacity 50% r.h. [%]	28.1	30.7
CO <sub>2</sub> Adsorption Capacity 45 mbar/25°C [%]	12.6	13.6
Water Adsorption Kinetic at p/p <sub>0</sub> =0.03 (after 120 min.) [%]	17.0	19.2
Nitrogen Kinetic Value [1/s]	0.20	0.33

As is shown from these examples, there are surprising improvements in the performance of molecular sieve adsorbent blends using attapulgite binder produced from highly dispersed attapulgite fibers. This improvement in crush strength, adsorption kinetics and other characteristics as shown in the Examples was surprising and dramatic.

Although the invention has been described in detail, it is clearly understood that the same is by no way to be taken as a limitation. The scope of the present invention can only be limited by the appended claims.